BACHELOR OF TECHNOLOGY FINAL YEAR PROJECT REPORT

ON

REDUCTION OF IRON ORE PELLETS

Submitted in partial completion of the necessities for the degree of Bachelor of Technology in Metallurgical and Materials engineering

AT

Department of Metallurgical and Materials engineering

NIT Rourkela, 769008

Submitted by

Biswanath Nahak (111MM0372)

Nayan (111MM0442)

under supervision of

Professor. Mithilesh Kumar

Metallurgical & Materials Engineering

NIT Rourkela

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

CERTIFICATE

This is to attest that the thesis entitled "Reduction of Iron Ore Pellets" Give in to by Mr. Biswanath Nahak and Mr. Nayan in partial completion of the necessities for the degree of Bachelor of Technology in Metallurgical and Materials Engineering at NIT Rourkela is a credible work completed under my watch and direction. To the best of my insight and conviction, the matter epitomized is never submitted to other institute/organization for the grant of any degree/diploma.

Date: 7th May, 2015

Professor Mithilesh Kumar

Department of Metallurgical &

Materials Engineering,

NIT Rourkela

Content

List of figures

List of tables

ACKNOWLEDGEMENT

We feel very fortunate to have been given an opportunity to do project work under such expert people in NIT Rourkela on project title "**Reduction of Iron Ore pellet**".

At the very start, we want to express gratefulness toward NIT Rourkela, for the consent to undertake project and providing us with the required amenities without which the entire activity would have proved vain. We also want to express my sincere on account of every one of those earnest endeavors, direction, proficient supervision and invaluable specialized assistant has made this project a success. We wish to acknowledge with profound feeling of appreciation and obligation to **Prof. Mithilesh Kumar** for his outcome orientated direction in this project work. Shared comprehension, collaboration, wholehearted co-operation and sound tuning with him aided as a main push in attaining to this task.

We are also obliged to **Prof. Subash Chandra Mishra,** HOD, Department of Metallurgical and Materials engineering for his kind co-operation whenever required.

We are also proud to take privilege to express my thanks to the staff of department of Metallurgical and Materials, NIT Rourkela especially Mr. B. Nayak and also to all who have directly or indirectly extended their hand in the accomplishment of the project.

Biswanath Nahak (111MM0372)

Nayan (111MM0442)

Abstract

In this work, influence of temperature & reduction kinetic on extent of reduction of iron ore pellet of size 15-17 mm in diameter is observed. Iron ore fines of -72 mesh size is mixed with bentonite as binder for pellet preparation. Structural property of reduced iron ore pellet is observed. Reduction kinetics rises with increase of temperature. However with considerable duration of reduction, rate of reaction decreases. Change in volume of iron ore pellet rises with increase in temperature, however when reduction temperature ranges above 950°C, lesser extent of change in volume occurs. Activation energy obtained for reduction of iron ore (hematite) pellet is 10.04 kJ. Change in volume of iron ore pellet increase with reduction time and after reaching around 80-90% of reduction, amount of change in volume of pellet decreases.

Chapter 1

Introduction

1. Introduction

Starting from the structural, construction, automobile, railways & other uncountable thing steel is most broadly used material. Steel exhibit range of the properties and most versatile material among all other material present. Consumption of steel of country represent economic status of country [3]. China is leading producer of steel followed by Japan. According to report published, India is ranked 4th for quantity of production of steel. The development of the steel business altogether helps monetary development and provides job to large number of technical person.

Now a days for iron making, Blast furnace is dominantly used for molten metal formation. Raw materials procured for iron making are iron ore lumps and also sinter, pellets are used. Hematite is widely chosen for iron ore by the industries as India has huge reservoir of Hematite and good iron content in it. In the process of extraction of ores in the mines a large portion of ore wasted as ore fines. So for optimal utilization of natural resource sinter and pellets are basically used. Fines were agglomerated in the method of pelletization in pelletizer plant for iron ore pellet.

Use of iron ore pellets and sinters have been significantly increased or say major proportion of iron containing charge in blast furnace is agglomerates because it allow us to use fine iron ore which cannot be used as it is because it will greatly affect porosity and hence working of Blast Furnace. Use of fluxed sintered helps in less consumption of energy for reduction purpose and hence less temperature profile for operating furnace.

The shortcoming related to the blast furnace methodology ignited the alternative process. Direct Reduction techniques have achieved some amount of share in manufacturing and are thought to be the good alternative option for making of iron.

1.1. Iron Ore Reservoir of India [2]

Iron ore reserve is distributed mostly in states of Jharkhand, Odisha, & Chhattisgarh. These Iron ore are present in above mentioned states are of best quality present in India. Following, table illustrate distribution of iron ore reserve state wise in India. (In thousand tonne)

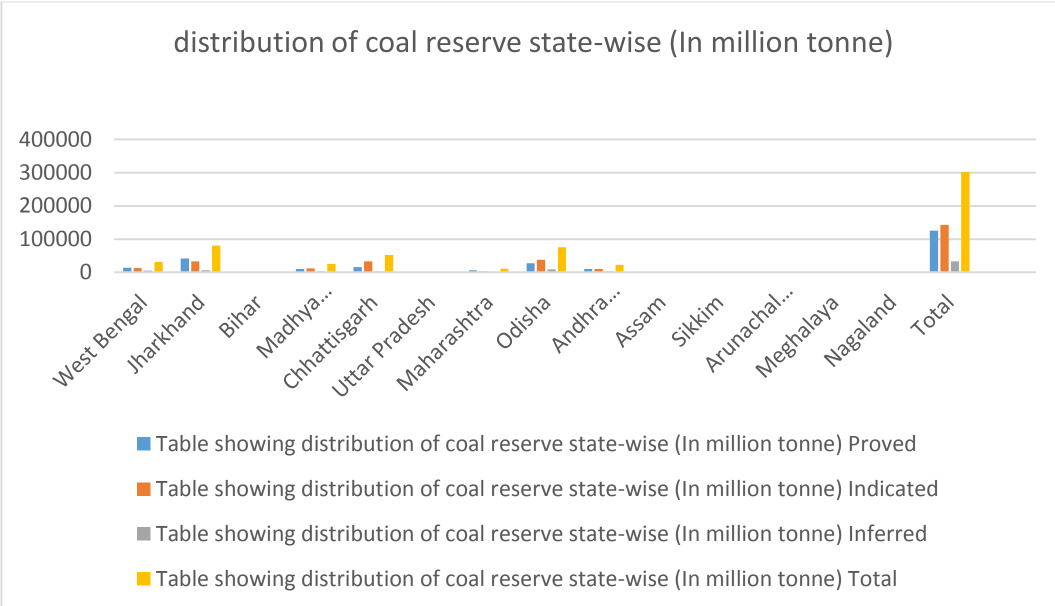
State	Hematite Reserve	Magnetite Reserve
Andhra Pradesh	381477	1463541
Assam	12600	15380
Bihar	55	2659
Chhattisgarh	3291824	0
Goa	927171	222673
Jharkhand	4596621	10542
Karnataka	2158677	7801744
Kerala	0	83435
Madhya Pradesh	231445	0
Maharashtra	283208	1360
Meghalaya	225	3380
Nagaland	0	5280
Odisha	5930233	199
Rajasthan	30561	526830
Tamil Nadu	0	507037
Uttar Pradesh	38000	0
India	17882097	10644061

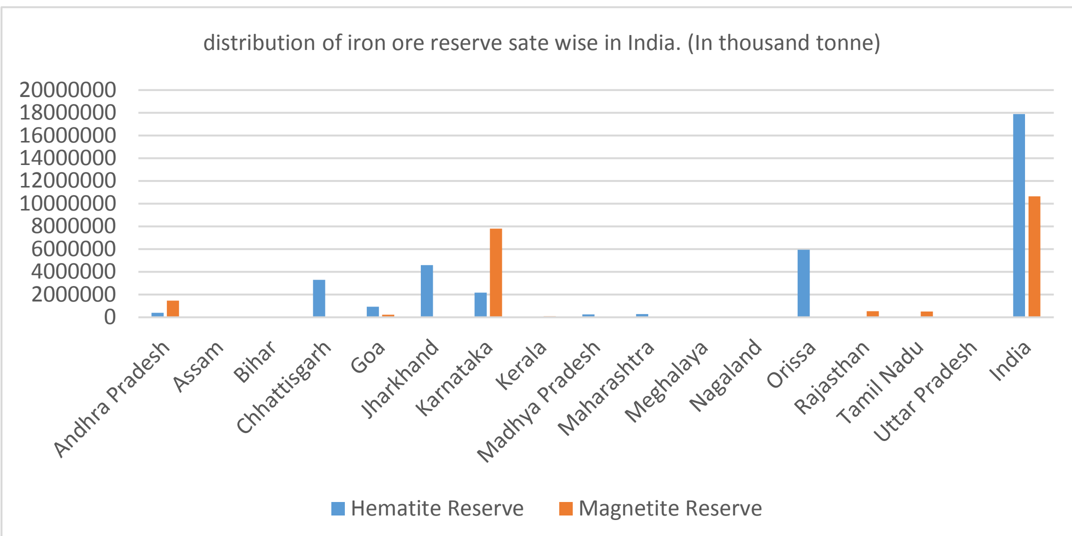
1.2. Coal Reserves of India [1]

Investigation were completed up to the most extreme profundity of 1200m which demonstrated that an aggregate of 301.56 billion ton of coal in our nation as on April 1 of 2014. The huge wellspring of coal in India are accessible in more established Gondwana arrangement of peninsular India and more tertiary establishment of north eastern area

Table showing distribution of coal reserve state-wise (In million tonne)

State	Proved	Indicated	Inferred	Total
West Bengal	13403	13022	4893	31318
Jharkhand	41377	32780	6559	80716
Bihar	0	0	160	160
Madhya Pradesh	10411	12382	2879	25673
Chhattisgarh	16052	33253	3228	52533
Uttar Pradesh	884	178	0	1062
Maharashtra	5667	3186	2110	10964
Odisha	27791	37873	9408	75073
Andhra Pradesh	9729	9670	3068	22468
Assam	465	47	3	515
Sikkim	0	58	43	101
Arunachal Pradesh	31	40	19	90
Meghalaya	89	17	471	576
Nagaland	9	0	307	315
Total	125909	142506	33149	301564


distribution of coal reserve state-wise (In million tonne)
400000
300000
200000
100000
0
West Bengal
Jharkhand
Bihar
Madhya...
Chhattisgarh
Uttar Pradesh
Maharashtra
Odisha
Andhra...
Assam
Sikkim
Arunachal...
Meghalaya
Nagaland
Total
Table showing distribution of coal reserve state-wise (In million tonne) Proved
Table showing distribution of coal reserve state-wise (In million tonne) Indicated
Table showing distribution of coal reserve state-wise (In million tonne) Inferred
Table showing distribution of coal reserve state-wise (In million tonne) Total


distribution of iron ore reserve sate wise in India. (In thousand tonne)
20000000
18000000
16000000
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
Andhra Pradesh
Assam
Bihar
Chhattisgarh
Goa
Jharkhand
Karnataka
Kerala
Madhya Pradesh
Maharashtra
Meghalaya
Nagaland
Orissa
Rajasthan
Tamil Nadu
Uttar Pradesh
India
Hematite Reserve
Magnetite Reserve

1.3. Goal of Project Work

This project work has been commenced to detect following

1) Influence of temperature on reduction reaction of iron ore pellet
2) Influence of kinetic on reduction reaction of hematite iron ore pellet.
3) % change in volume of iron ore pellet during reaction
4) To compute activation energy for reaction of reduction of iron ore pellet.

Chapter 2

Literature review

2. Literature Review

Various Chemical reaction which takes place for formation of iron are as follow

Fe_2O_3(s) + C (s) = Fe(s) + CO (g)

This reaction is commonly acknowledged as direct reduction. Here carbon itself react with iron oxide.

Beside carbon monoxide gas as reducing agent H_2 also acts as an alternative reducing agent. Reaction with hydrogen is endothermic reaction. Reaction for hydrogen formation in reduction atmosphere is

C(s) + H_2O (g) →H_2 (g) +CO (g)

Reaction for reduction of hematite and magnetite formation

Fe_2O_3(s) + CO/H_2 (g) →2Fe_3O_4 + CO_2/H_2O

Reaction for reduction of magnetite and wustite formation

Fe_3O_4(s) + CO/H_2 (g) →3FeO+CO2/H_2O

Reaction for reduction of wustite Phase & and Iron formation

FeO(s) + CO/H_2 (g) → Fe + CO_2/H_2O

2.1. Reaction Kinetic [5][6][7]

Work carried out by Mithilesh Kumar et-al have reported that rate of reduction were enhanced with the surge of temperature and reduction rate were elevated at the beginning of reduction reaction. Mixing of large size Hematite iron ore with -100 mesh fines helps in reducing activation energy and hence rise in reduction rate. Reduction of iron ore pellet in char as well as coal atmosphere were performed & kinetic were great in coal atmosphere[5] .Y Man et-al working on temperature & time impact on reduction have reported that below 900°C, reduction process is controlled by diffusion. They also stated that rate of reduction decreases with duration of time of reduction and change in mechanism of reduction after 900°C. Mechanism name given by him in different temperature range are follow:-

i) $\leq$ 900°C - Diffusion

ii) 900°C $\geq$ T$\leq$1100°C Mixed control

iii) $\geq$ 1100°C - Phase boundary[6]

Rusila Zamani Abd Rashid et-al study reported that iron ore containing iron oxide hydrate was altered into hematite and then magnetite upon heating. Work were carried out to see influence of temperature on kinetic of poor grade iron ore using energy source as a biomass waste and established it as effective method. Use of biomass will reduce discharge of carbon dioxide and advancement of iron ore [7].

2.2. Factors affecting reduction rate of iron ore [5]

i) Flow rate of CO gas.

ii) Crystal structure of iron ore pellet

iii) Caking index of coal

iv) temperature & duration of reduction

v) Ash fusion temperature & reactivity of coal

vi) Period of connection between reducing gases and iron ore pellet

vii) porosity, reducibility & size

2.3. Change in volume of iron Ore pellet [4][9][10][11][12]

On change in volume of pellet, report given by LYi et al. states that change in volume of pellet rises with escalation of temperature and CO content in atmosphere. Whereas, in case of hydrogen change in volume was not considerable because wustite phase fade hastily after its creation. Reason behind change in volume of iron ore pellets is creation of iron whisker in CO atmosphere. Change in volume of pellet occur due to formation of iron whiskers [4]. S Dwarapudi et-al investigation reported that fluxing has significant influence on change in volume of pellet. Amount of change of volume of pellet were weakened with fluxing. [9]. Run-Sheng XU et-al investigating on change in volume behavior reported that during reduction RSI increases and then decreases. Though increasing the Hydrogen content in reduction atmosphere decreases RSI but enough increase of hydrogen content in atmosphere will bring cracking of pellets [10]. Saroj K. Patel et-al investigated that change in volume of pellets made up of varying fines size (-100 to +100 mesh size) is somewhat more than that made up of fines of -100 mesh size. Extent of change in volume were found lesser for pellets whose reduction were carried out at higher temperature i.e. temperature at 950°C and 1000°C and with span of reduction time change in volume of pellet got reduced[11].

.

Carlos E Seaton et-al. had studied change in structure during reduction and reported that whisker formation, which causes change in volume in iron ore, occur due to alteration in reduction potential of the gas segment inside pellet together with available CaO on the wustite layer. Drop in change in volume was noticed with increasing temperature of reduction and reason being agglomeration of filament of iron [12].

Change in volume behavior while reduction is only observed in reduction of iron ore pellet. Change in volume of iron ore pellet affects adversely working of furnace. However 20% change in volume of iron ore pellet is acceptable and tolerated. Numerous researcher proposed cause of change in volume of iron ore pellet during reduction, nonetheless, the altered reasons for change in volume, as proposed are [11]

i) Change in structure of iron ore pellet during reduction
ii) formation of iron whisker in CO atmosphere

iii) breakdown of grains of iron

iv) generation of crack

v) Porosity, crushing strength, other physical property of iron ore pellet

vi) Degree of reduction

vii) Reduction parameter

viii) Agglomeration parameter

ix) Sintering/recrystallization of iron ore grains

Chapter 3
Experimental work

3. Experimental Work

- Coal & Iron Ore selection: Iron ore and coal were collected from Sakaruddin and Jagannath mines of Odisha respectively.
- Proximate analysis of coal: Proximate analysis of jagannath mine coal was done jointly with Kishore Kumar Behera, NIT Rourkela.

  Moisture content = 8.37%

  Volatile material = 35.31%

  Ash content = 18.08%

  Fixed carbon content = 38.24 %
- Chemical composition Determination of Iron ore:

  Chemical composition was found in Rourkela steel plant.[5]

  Table.3.1: chemical composition of Hematite Iron ore from Sakaruddin mine

Name of Iron ore mines	Iron (Fe)	Hematite (Fe_2O_3)	Alumina (Al_2O_3)	Silica (SiO_2)	Titanium Dioxide (TiO_2)	Manganese II Oxide (MnO)	Loss on ignition (LOI)
Sakaruddin	64.50	91.74	3.06	1.43	0.14	0.02	3.61

- Iron ore pellets Preparation: Iron ore were wrinkled into small fines by using pestle and mortar. Iron ore fines of -72 mesh size were mixed with Bentonite by 2 weight percentage as binder. Then water was mixed with it and pellets were made by hand rolling of moisturized fines. The diameter of pellets were between 15-17mm of total 20 pellets. Pellets were air dried for 24 hrs. & dried for 2 hrs. in furnace at 100 °C. Then pellets were fired at 1000°C for 1 hr. in furnace.
- Procedure of reduction studies and swelling: Fired iron ore pellets were preheated at 100°C in a furnace for 1hr. The non coking coal was crushed to -72 mesh size. Then in stainless steel reactor of 8mm diameter and 15mm height was taken. The coal and an iron ore pellet were put together in the reactor, the pellet was placed in the center of the coal.

Some space of the reactor was left blank after filling coal and pellet. The lid of the reactor has a hole as an outlet for discharge of gas.

Then the muffle furnace was set to required temperature and after reaching the required temperature, then three reactor with sample were placed inside the furnace. And reduction was carried out for 30, 60, 90 minutes respectively. The reactors were removed from the furnace as 30 minutes interval. In this way pellets were reduced for 850,900,950°C respectively. After reduction the pellets were left for some time to cool down. Then amount of reduction was computed by percentage weight of oxygen removed. Then swelling was calculated by measuring diameter of pellets before and after reduction.

$$\% \text{ Reduction} = \frac{\text{weight loss during reduction}}{\text{weight loss due to oxygen removal}} \times 100\ \%$$

$$\% \text{ Swelling} = \frac{\text{Vo} - \text{Vi}}{\text{Vi}} \times 100\ \%$$

Where V_o = volume of pellet after reduction

V_i = volume of pellet before reduction

- Scanning electron microscopic study:

The internal zone of reduced pellet was seen in scanning electron microscope. The scanning electron microscope was of JEOL 8905 made in japan. At first we had prepared the sample of required size. The sample had a dimension of about 5-6mm in diameter and 1-2mm in thickness. Then the sample was fixed onto the sample holder by sticky carbon tape & the electron beam incident on the sample to make it electrically conducting for SEM analysis.

Chapter 4
Result & Discussion

4. Result and Discussion

Table.4.1: Data obtained from reduction of Iron ore pellets

Sl no	Reduction temperature	Reduction time in minutes	% reduction	% swelling
1	850^{0}C	30	62.28	27.00
		60	74.89	53.69
		90	81.73	51.58
2	900^{0}C	30	62.90	35.34
		60	82.68	47.38
		90	92.98	39.19
3	950^{0}C	30	81.35	11.45
		60	93.11	28.09
		90	99.08	49.94

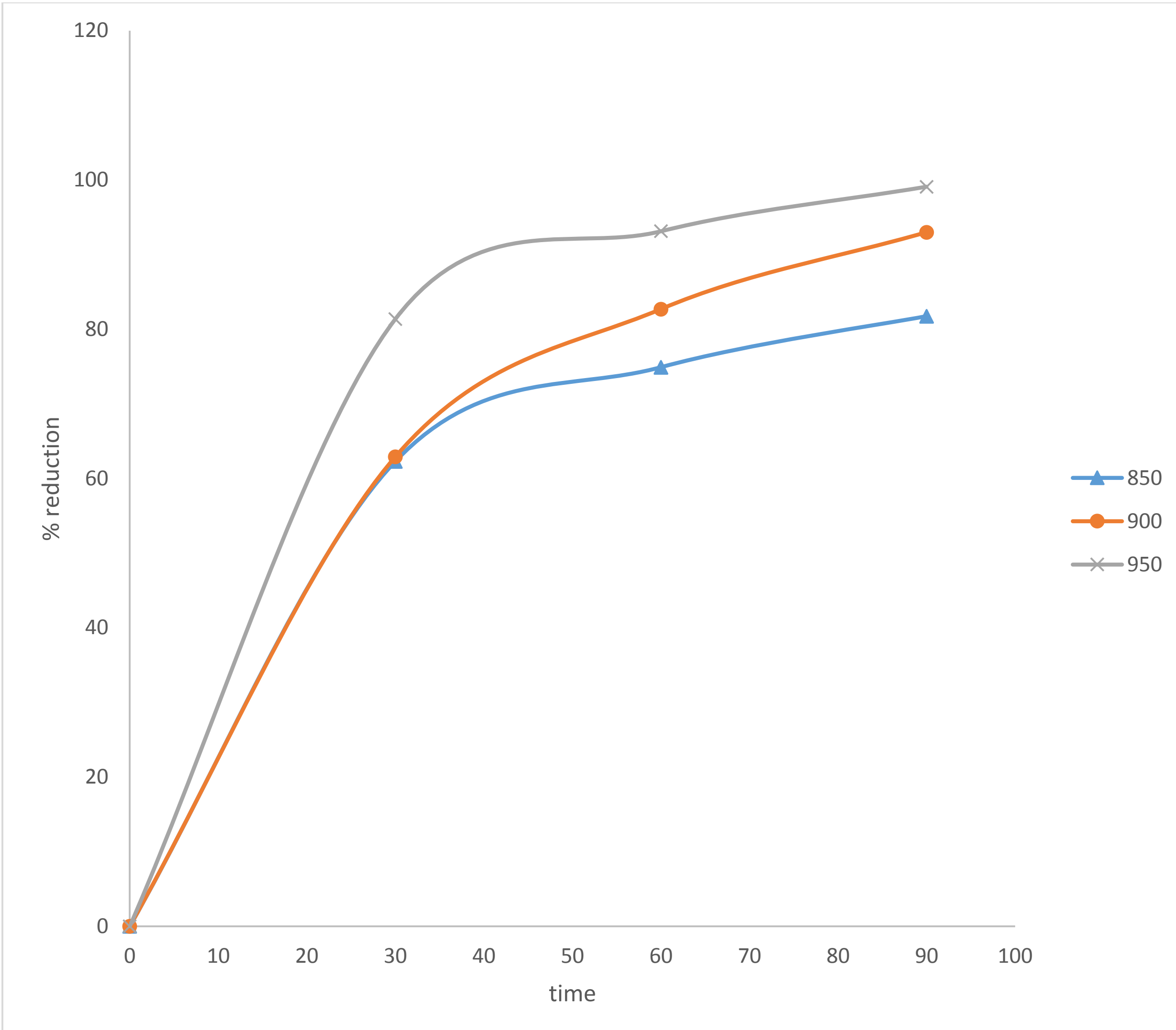


Figure.4.1: % reduction vs time

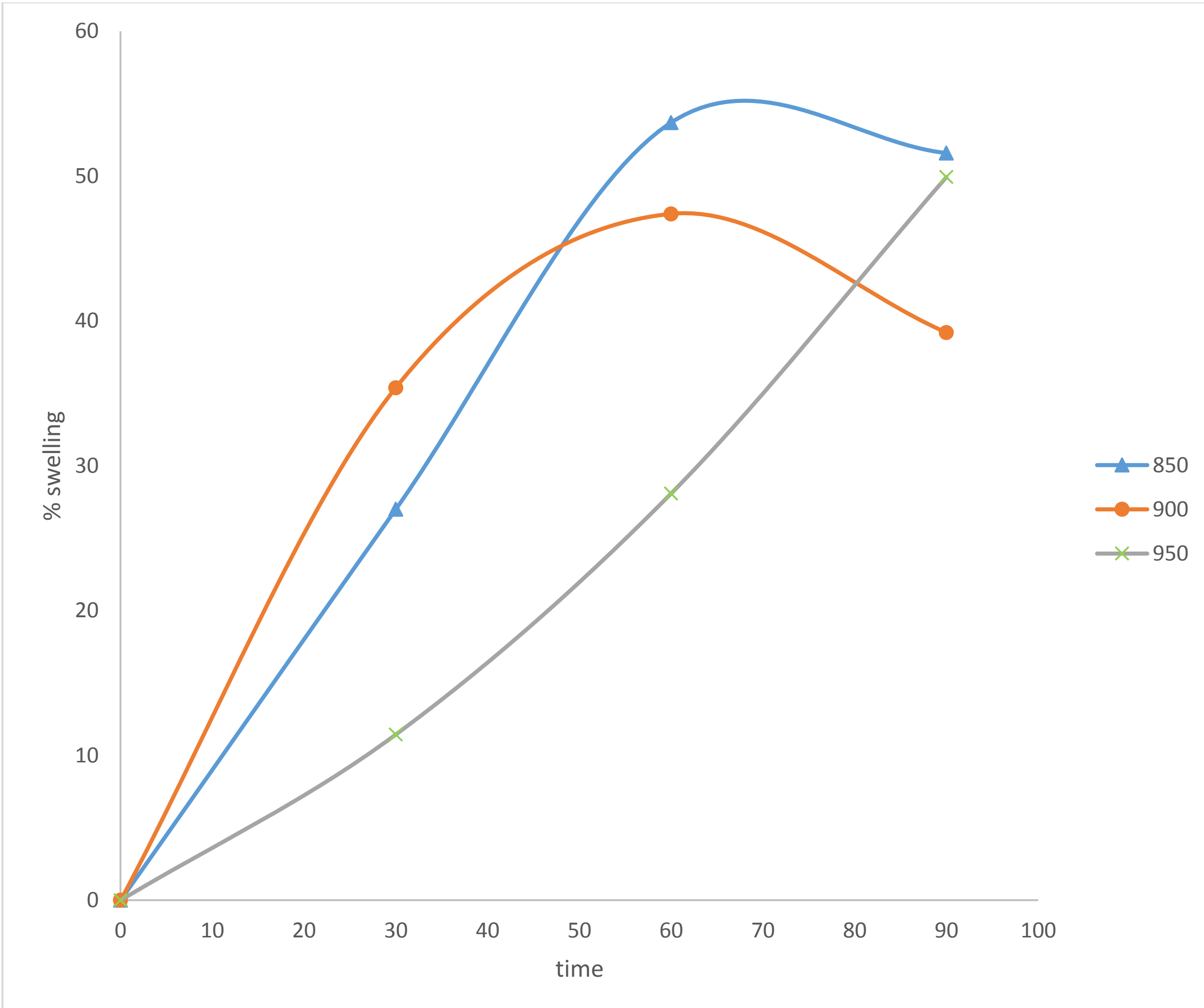


Figure.4.2: % swelling vs time

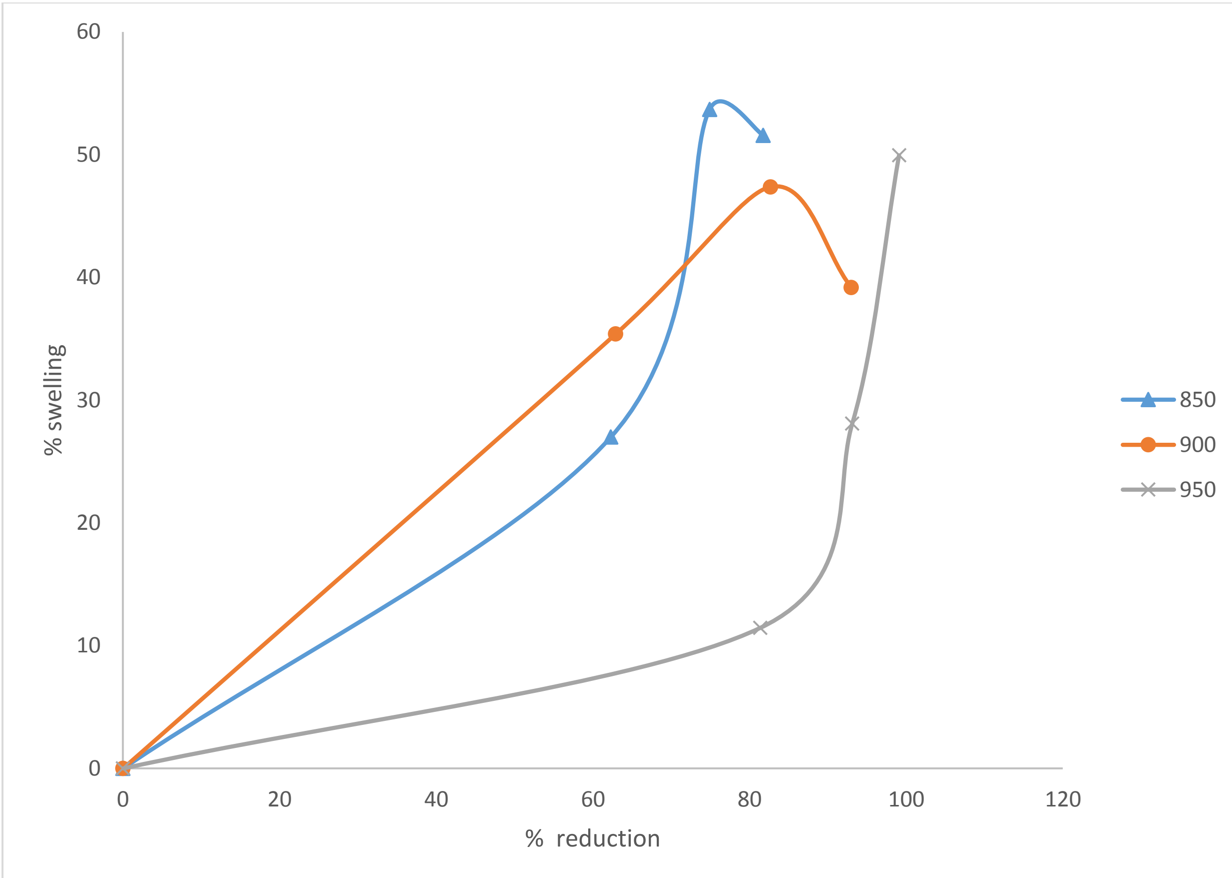


Figure.4.3: % swelling vs % reduction

Table.4.2:

Time (in minutes)	-ln(1-f) Where f = degree of reduction		
	850°C	900°C	950°C
0	0	0	0
30	0.97498	0.991553	1.679324
60	1.381904	1.753308	2.675099
90	1.69991	2.655407	4.688552

Table.4.3:

-lnK	Temperature (k^{-1}) $\frac{1}{T} \times 10^{-4}$
3.863	8.9
3.516	8.53
2.991	8.18

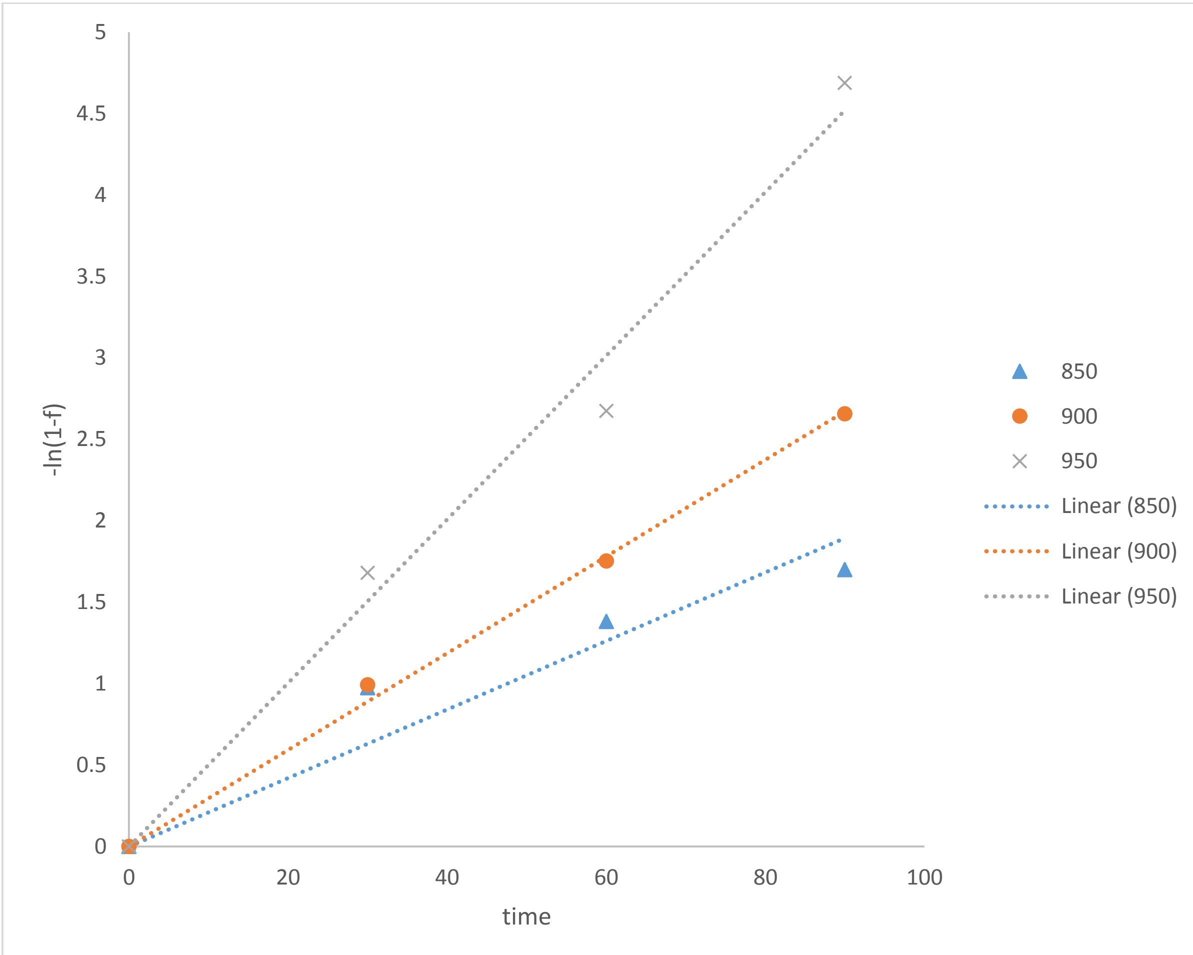


Figure.4.4: Chemically controlled reaction kinetics

Calculation of K:

K is calculated from the slope of above plot.

$$-\ln(1-f) = Kt$$

For T = 850^{o}C , K = 0.021

T = 900^{o}C , K = 0.0297

T = 950^{o}C , K = 0.0502

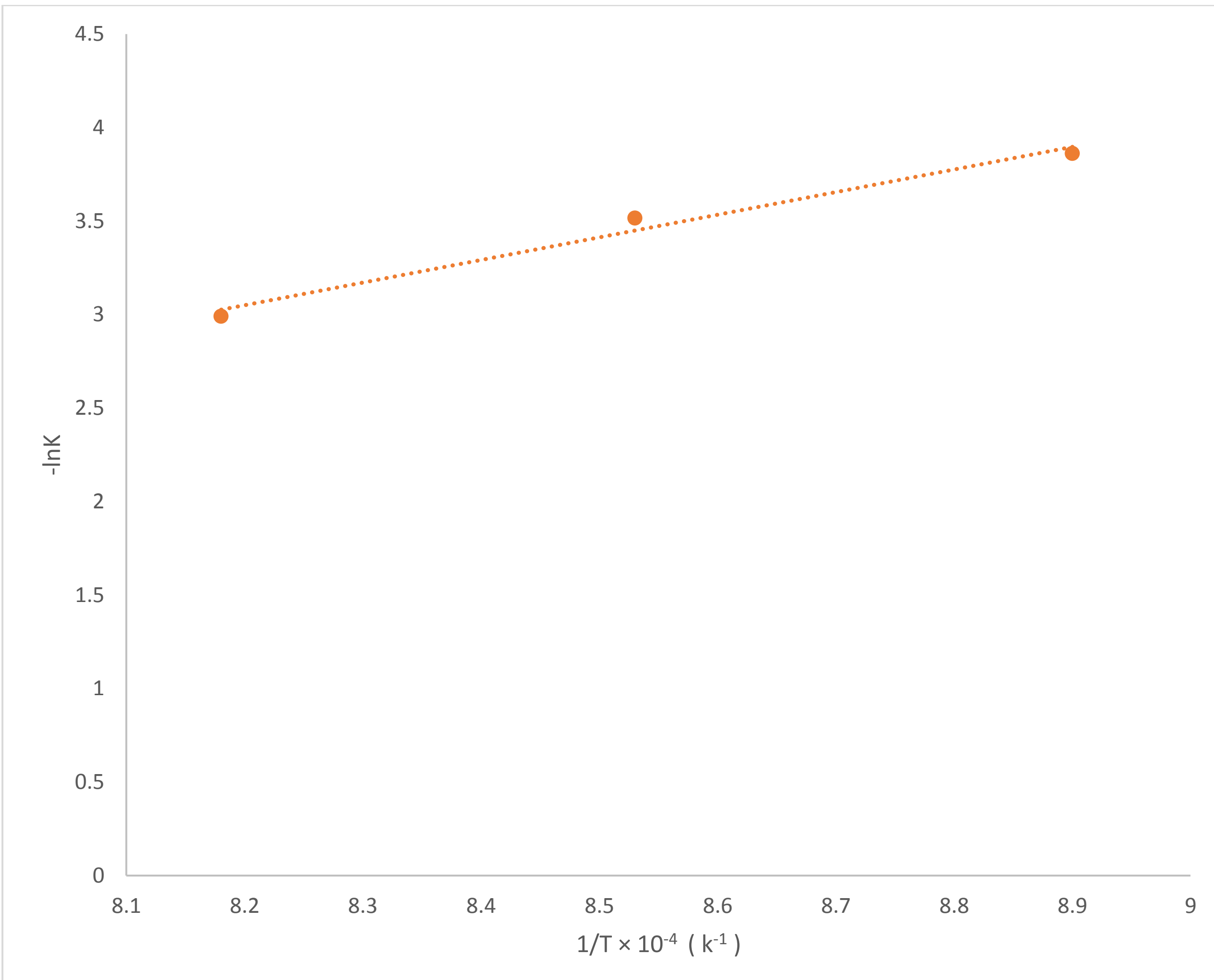


Figure.4.5: Rate constant vs temperature

Activation energy

We plotted –lnK vs $\frac{1}{T} \times 10^{-4}$ in the above figure 5.

Activation energy can be calculated from Arrhenius equation.

$K = Ae^{-E/RT}$

Where K = reaction rate constant

A = Arrhenius constant

E = activation energy

R = universal gas constant = 8.314 J mol^{-1} K^{-1}

$-\ln K = \frac{E}{RT} - \ln A$

Activation energy E = slope of the plot $\times R$

E = 10.04 kJ

Hence calculated activation energy for reduction of reaction is 10.04 kJ

SEM IMAGES

SEM images of reduced iron ore pellet at 15kv energy & 1500x magnification

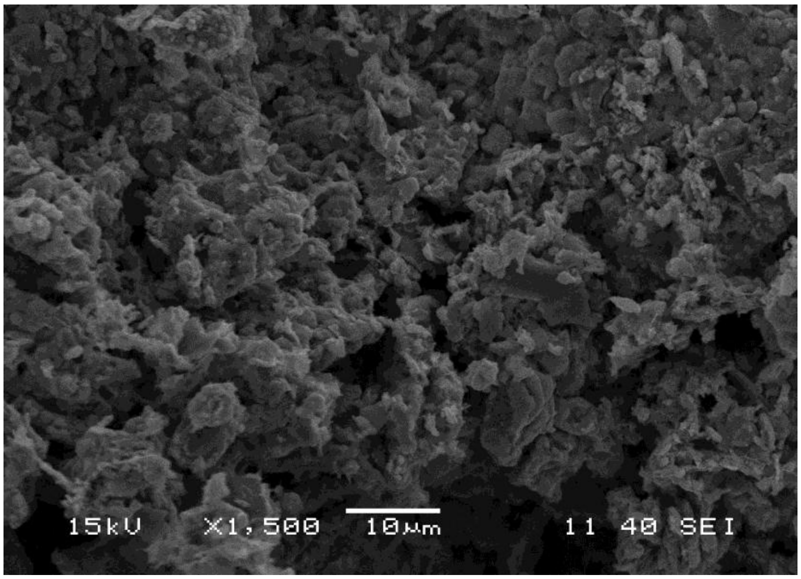


Figure.4.6: 850°C at 90 minutes

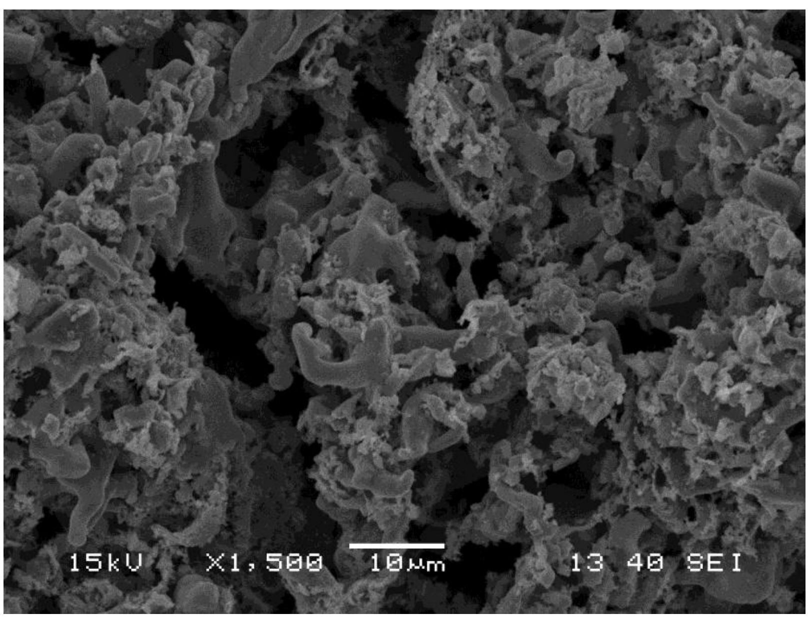


Figure.4.7: 900°C at 60 minutes

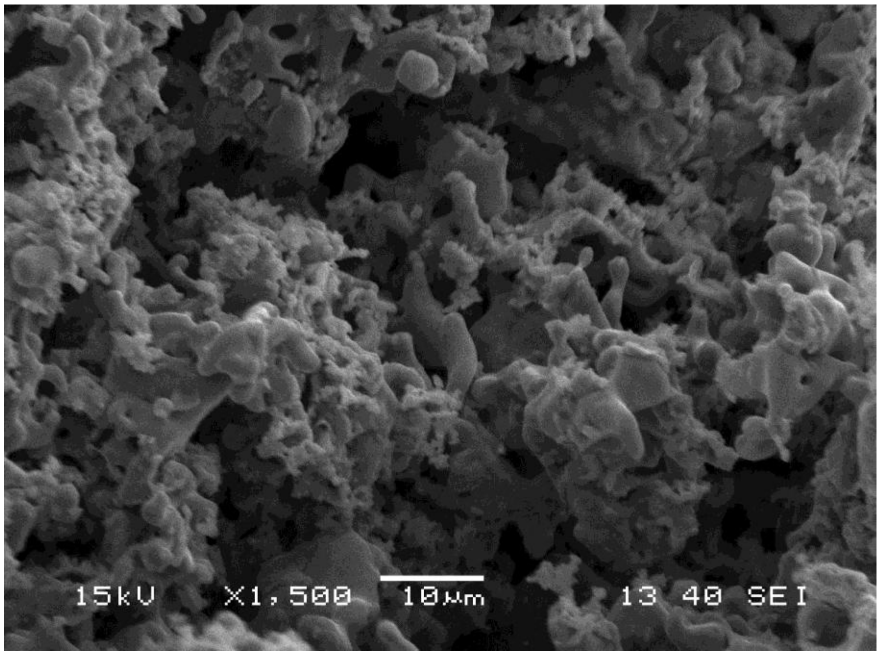


Figure.4.8: 950°C at 60 minutes

SEM study of reduced iron ore pellets

The SEM micro graph of some of the iron ore pellet reduced at temperature of 850°C (90 minutes) , 900°C (60 minutes) and 950°C (60 minutes) have been presented in figure.4.6, 4.7 and 4.8. The formation of iron nuclei and their sintering are quite evident in these figures. The formation and sintering of iron nuclei got increases with rise of temperature.

4.1. Influence of time & temperature on amount of reduction

The degree of reduction of fired iron ore pellet first increases rapidly with increase of time up to about 30-40 minutes followed by a decrease thereafter. The higher rate of reduction in the first 30-40 minutes is due to the followings:

i) Faster diffusion of reducing gases (CO & H_2) and solid carbon inside the iron ore pellets.

ii) Opening up of the pores and formation of cracks inside the iron ore pellet during reduction. The opening up pores and formation of cracks allow more and more diffusion of reductants inside the pellets.

The decrease in rate of reduction in the later stages of reduction is due to the following:

i) Increase in the thickness of iron layer over the reduced pellets. This hinders of the flow of reductants to the surface of unreduced iron oxide.

ii) Sintering of the pores.

As shown in figure 4.1, the degree of reduction increased with increase of temperature. 100% reduction at temperature of 900°C was obtained in an approximately 90-100 minutes whereas at 950°C, this time got reduced to 20-25minutes.

During the course of heating, the coal particles get devolatized and reducing gases (CO & H_2) get generated inside the reactor. With increase of temperature, the rate of diffusion of the reducing gases and solid carbon inside the fired iron ore pellet get enhanced and thus rate of reduction increases.

4.2. Influence of swelling on temperature and degree of reduction

The result of swelling of fired iron ore pellets obtained in the present reduction studies are shown in figure 4.2 and 4.3. These figures indicate about the effects of reduction temperature and time on % swelling.

Reason for increase of % swelling

i) Due to fibrous growth of iron

ii) Due to presence of more pores

iii) Formation of cracks

During later stage of reduction and at higher temperature there has been decrease in extent of swelling iron ore pellet because of the followings:

i) Sintering of iron nuclei formed

ii) Hindrance in the fibrous growth of iron

Chapter 5
Conclusion

5. Conclusion

- The % reduction of Hematite iron ore pellets increases with time and decreases later during reduction of pellet
- Also the % reduction of pellets increases with temperature in the range of 850-950°C.
- The swelling index of reduced pellets increases up to 60 minutes and then decreases with rise in temperature as well as time
- The swelling index of reduced pellets increases up to certain limit of degree of reduction & afterwards decreases.
- Activation energy of the reduced pellets during reduction reaction has been calculated. & found out to be 10.04kJ.

Chapter 6
References

Reference-

1) WWW. Coal.nic.in- Ministry of mines, Government of India
2) Indian Bureau of Mines , Ministry of mines, Government of India
3) Jindal stainless steel, 4jindal Kalinga Nagar. Pdf
4) Yi, Lingyun, Huang, Zhucheng, Jiang, Tao, Wang ,Lina and Qi ,Tao, swelling behavior of iron ore pellet reduced by Hydrogen and carbon monoxide mixture, Powder technology, 269, 2014, pp. 290-295
5) Kumar, M, Mohapatra, P and Patel, S.K “Studies on the reduction kinetics of Hematite Iron ore pellets with Non coking coals for sponge iron Plant, Tylor and Francis group, LLC,30, 2009, pp. 372-392
6) Man,Y, Feng, J.X., Li, F.J., Ge, Q., Chen, Y.M. and Zhou, J.Z., Influence of temperature and time on reduction behavior in Iron ore-coal composite pellets, powder technology, 256,2014, pp. 361-366
7) Rusila Zamani Abd Rashid, Hamzah Mohd. Salleh, Mohd Hanafi Ani a, Nurul Azhani Yunus a, Tomohiro Akiyama b, Hadi Purwanto “Reduction of low grade iron ore pellet using palm kernel shell, Renewable energy, 63, 2014, pp. 617-623
8) Biswas, A.K, Principles of Blast Furnace Iromaking, SBA Publications, Calcutta, 1981
9) Dwarapudi, S, Banarjee P.K, Chaudhary, Pradip, Sinha Surajit, Chakraborty, Ujjal Sekhar, Chandra, Venugopalan, T and Venugopalan R, Effect of Fluxing agents on swelling behavior of hematite pellets, International Journal of Mineral Processing, 126, 2014 pp. 76-89
10) XU, Run-Sheng, Zhang, Jian-Lian, ZUO, Hai-Bin, JIAO, Ke-xin, HU, Zheng-wen and XING Xiang-don, Mechanisms of Swelling of Iron Ore Oxidized Pellets in High Reduction Potential Atmosphere, Journal of iron and steel Research, 22.1, 2015. pp. 1-8
11) Patel, S.K., Bhagel, Himanshu and Kumar, M, Reduction and swelling of fired hematite iron ore pellets by non-coking coal fines for application in sponge iron making, Tylor and francis group, LLC, 34, 2013, pp. 249-267
12) Seaton, Carlos E, Foster, James S. and Velasco, Julio, Structural changes occurring during reduction of Hematite and magnetite pellets containing coal char, 23, 1983, pp. 497-503